ACCP suborbital component – Aerosol

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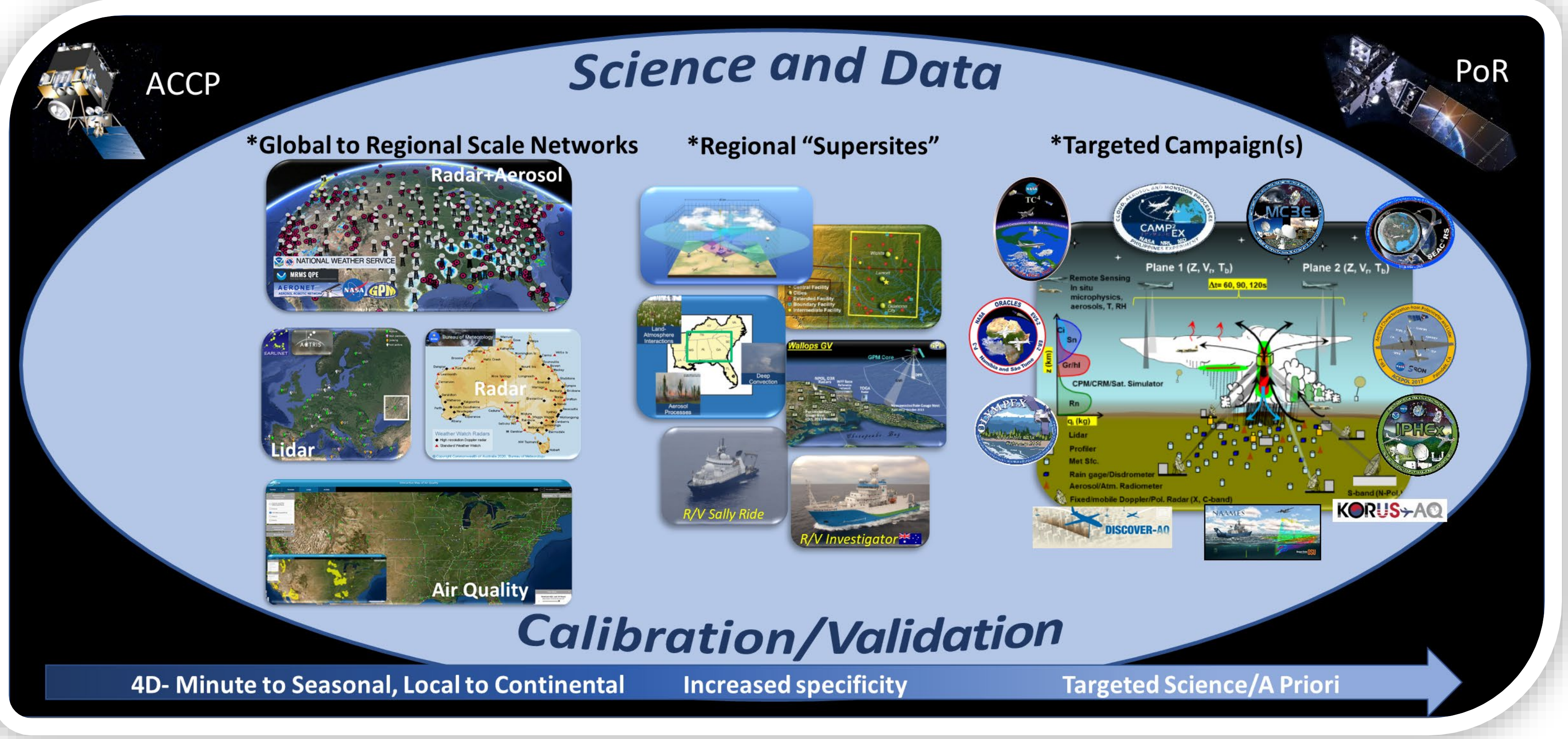
Role and Status of Suborbital Activities

Background

Suborbital activities are an integral part of ACCP science and have to fulfill multiple purposes:

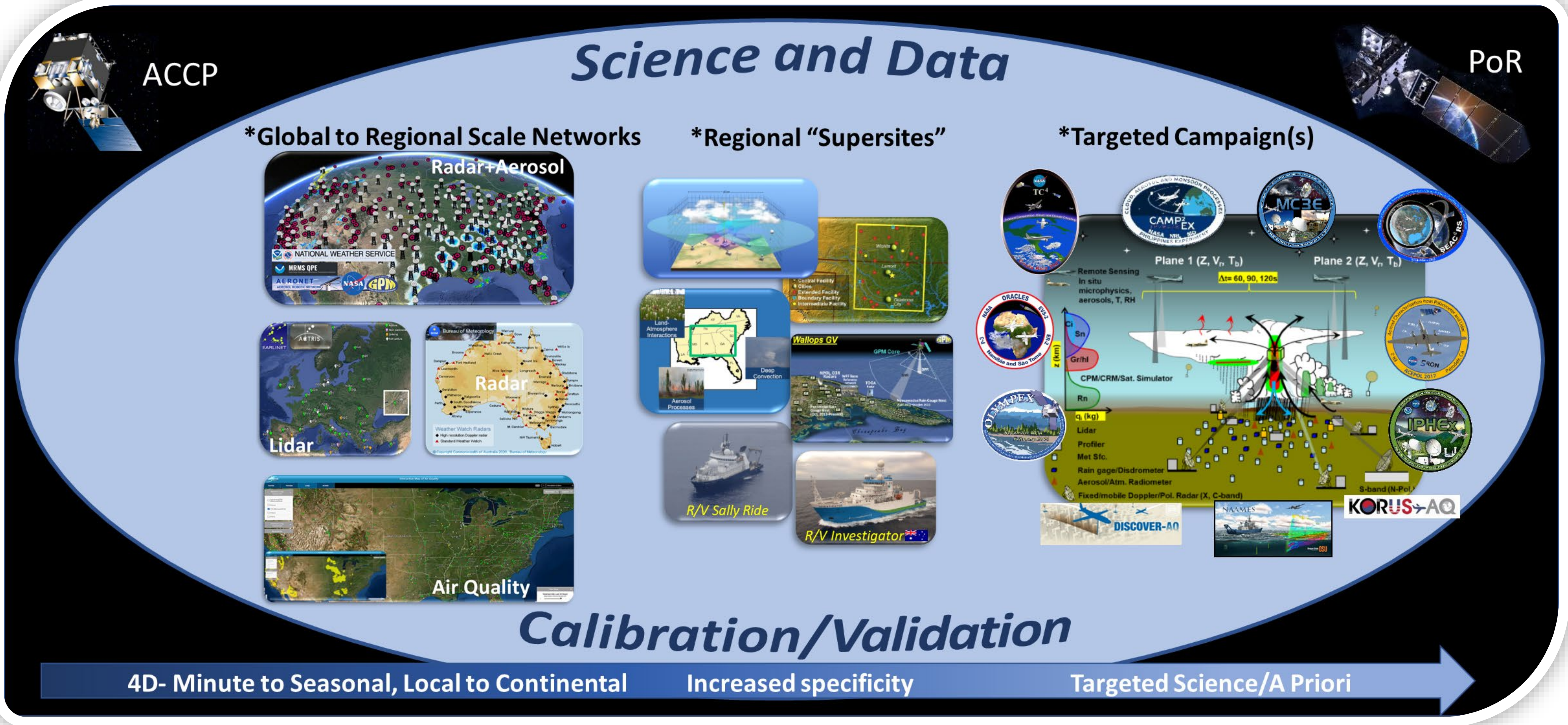
- Provide science that is best, better, or only done from sub-orbital vantage point
- provide priors for/utility to algorithms
- provide synergies for Cal/val
- Ideally bridge gaps between PoR and/or launch schedule



Status

- Two workshops conducted during Observable Study
  - Workshop 1 (March 2020): Scope of suborbital
  - Workshop 2 (March 2021): Implementation approaches
- Given scope of ACCP science and complexity of instruments, initial suborbital budget makes synergies essential

Broad Spectrum of Implementations Possible



Scope of the 2nd SOWG Workshop

Workshop 2

Objectives: **Seeking Community input on the suborbital implementation concepts that address the science identified in Workshop 1**

- Because…
  - There is vastly more suborbital science that *could* be done than what is possible (given anticipated budget)
  - ACCP has specific science objectives that require Suborbital to achieve (what suborbital prioritizes must be traceable back to the SATM)
  - Not all decisions have yet been made regarding orbital assets
- **We need a spectrum of implementation concepts for each science theme**

A spectrum of implementation concepts

$ **1. Explore Existing data sets (surface and airborne):**

- what are they and how can they contribute to ACCP orbital science?

$$ **2. Existing and planned surface measurement capabilities ACCP can leverage**

- Surface-based Partnerships: E.g., ARM Permanent and Mobile, AERONET, EARLINET, MPLNET, ship campaigns with piggyback deployments of SOWG assets (ODP program?), NOAA MRMS operational radar network products and similar international efforts/data streams etc.
- ACCP-led surface-based Deployment of measurement suites with existing mobile instrumentation

$$$ **3. Participate/Partner in airborne campaigns (i.e., EVS, interagency, international)**

$$$$ **4. Major Deployments: Multiple, single, or systematic airborne campaigns**

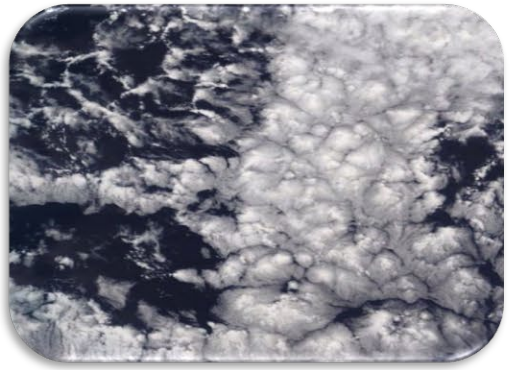
ACCP Science Themes and Modules

- Three science themes with *<u>highly</u> synergistic process* modules and a *Systematic aerosol sampling* module
- *Space-time resolved and in situ measurements,* airborne and/or surface-based platform accessible

Themes →

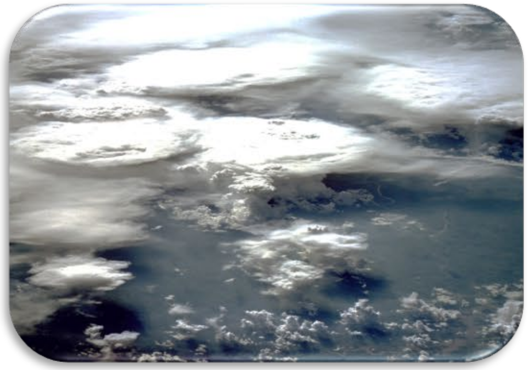
Cf. individual module files

Low Cloud/ACI



- Precipitation initiation in shallow Cumulus
- Open/Close cell transitions in marine stratocumulus
- Ice precipitation process in cold marine PBL clouds

Convection and High Cloud



- Convective core processes and environment controls
- Convective detrainment
- Anvil cirrus lifecycle

Cloud & Aerosol processes

- Vertically-resolved aerosol effects on cloud formation
- Impact of convection on aerosol redistribution and removal
- Influence of PBL on aerosol attribution and vertical redistribution

\+

Systematic Aerosol

- In situ aerosol profile
- Intensive properties
- Speciation
- Radiative properties

Workshop 2

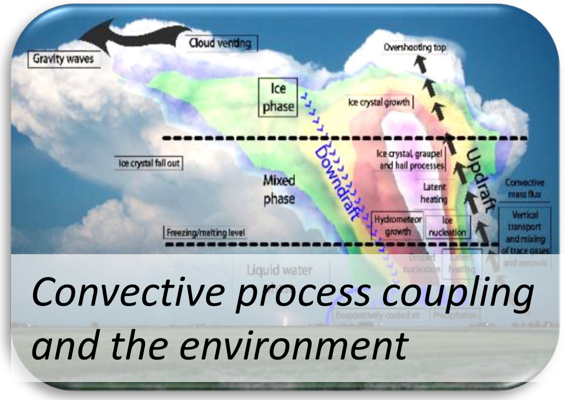
Implementation

- Prior Field Data
- Long Term Ground Based in situ and Remote Sensing
- Multi or focused single Aircraft Campaign
- Systematic Aircraft Measurement
- Ship-Based Remote Sensing
- Non-traditional (UAS, Balloon…)

SOWG Science Driver Overview: Motivation
Jens Redemann and Jay Mace

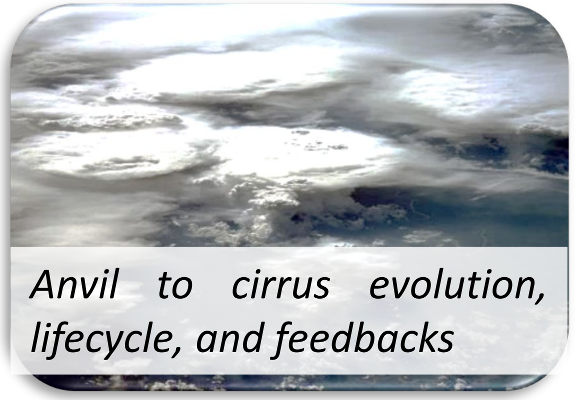
Modules →
Themes ↓

Convection and High Clouds

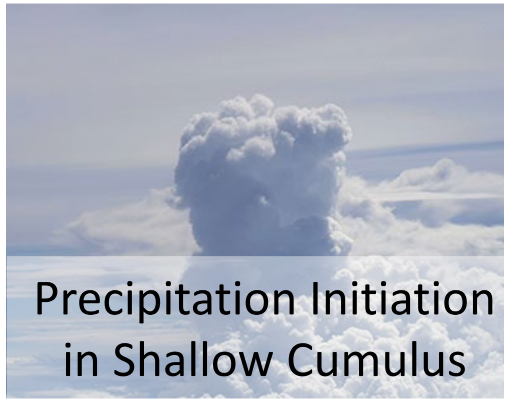


Convective process coupling and the environment

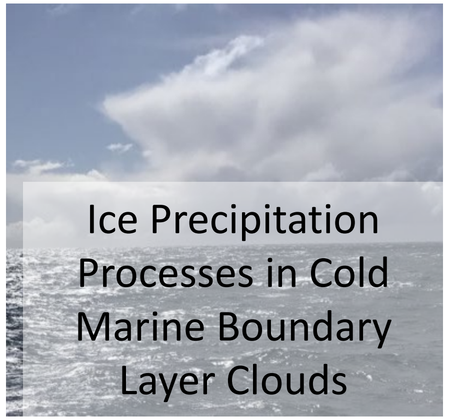

Convective core detrainment and anvil growth- character and process


Anvil to cirrus evolution, lifecycle, and feedbacks

Low Clouds/ACI

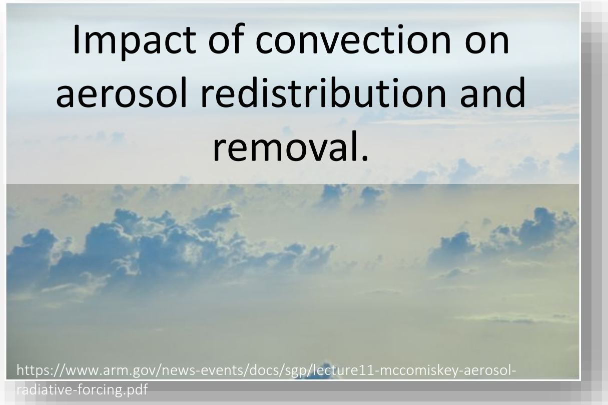

Precipitation Initiation in Shallow Cumulus


Open-Closed Cell Transition in marine Stratocumulus

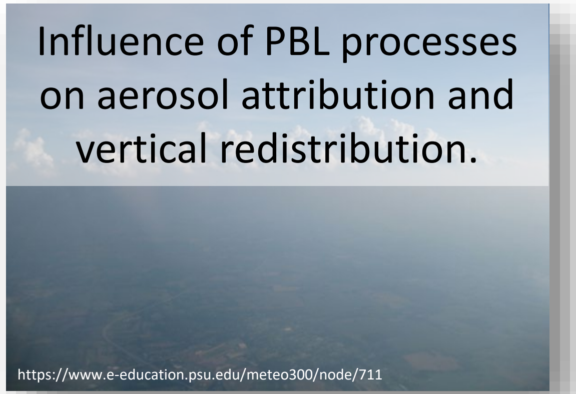

Ice Precipitation Processes in Cold Marine Boundary Layer Clouds

Cloud & Aerosol lifecycle and radiative processes

Vertically resolved aerosol effects on cloud formation.



Impact of convection on aerosol redistribution and removal.



Influence of PBL processes on aerosol attribution and vertical redistribution.

Traceability to ACCP SATM

ESD Focus Areas:
- Coupling of the water and energy cycles
- Extending and improving weather and air quality forecasts
- Reducing climate uncertainty and informing societal response

Goal 1: Reduce the uncertainty in low- and high-cloud climate feedbacks by advancing our ability to predict the properties of low and high clouds

O1: Low Cloud Feedbacks

Determine the sensitivity of boundary layer bulk/*microphysical* cloud physical and radiative properties to large-scale and local environmental factors including thermodynamic and dynamic properties.

Goal 4: Reduce uncertainty in key processes that link aerosols to weather, climate and air quality related impacts.

O5: Aerosol Attribution and Air-Quality

Quantify optical and microphysical aerosol properties in the PBL and free troposphere to improve process understanding, estimates of aerosol emissions, speciation, and predictions of near-surface particulate concentrations.

Enhanced: Characterize variations in vertical profiles of optical and microphysical properties over space and time in terms of 3D transport, spatially resolved emission sources and residual production and loss terms.

O6: Aerosol Processing, Wet Removal, Vertical Redistribution

Characterize the processing and wet removal and vertical redistribution of aerosols by clouds and light and moderate precipitation (< 5 mm/hr) and heavy precipitation (> 5 mm/hr).

Goal 5: Reduce the uncertainty in Direct and Indirect aerosol radiative forcing of the climate system.

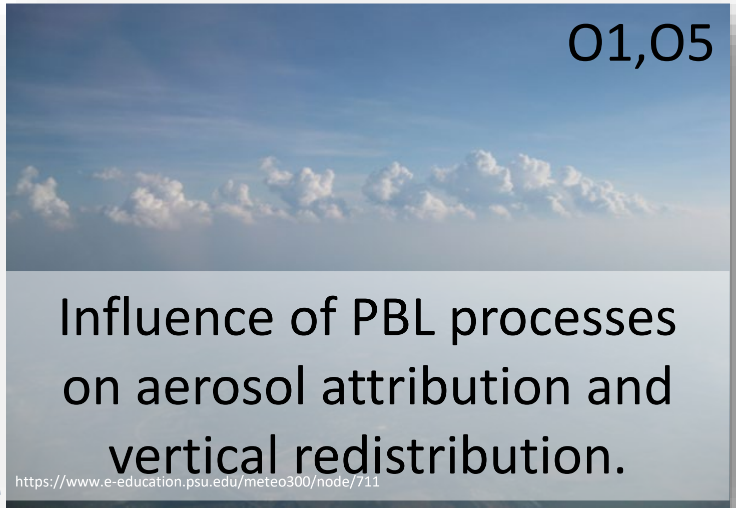
O7: Aerosol Direct Effect and Absorption

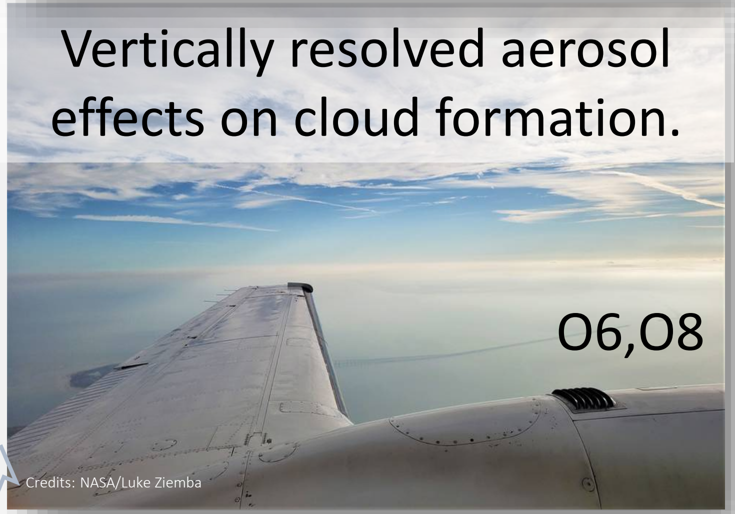
Reduce uncertainties in estimates of: 1) global mean clear and all-sky shortwave direct radiative effects (DRE) to ±1.2 W/m2 at TOA and the anthropogenic fraction, 2) regional TOA and surface DRE, and 3) Quantify the impacts of absorbing aerosol on atmospheric stability. Quantify the impact of absorbing aerosols on vertically resolved aerosol radiative heating rates and DRE commensurate with the uncertainties in global mean at TOA and surface.

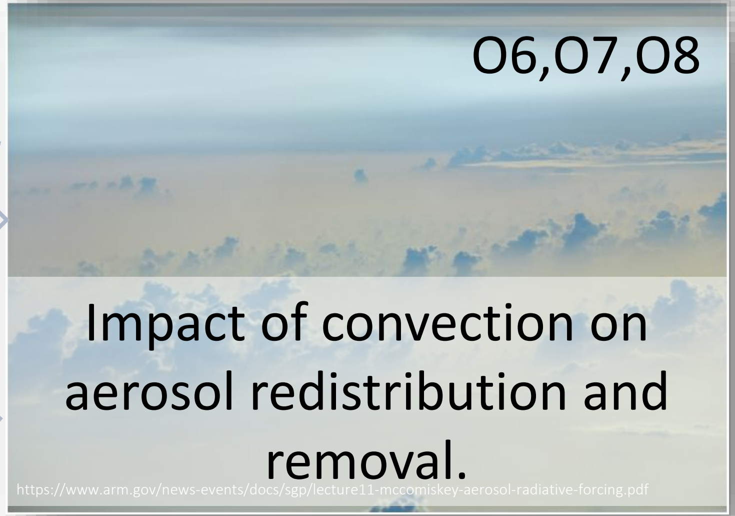
O8: Aerosol Indirect Effect

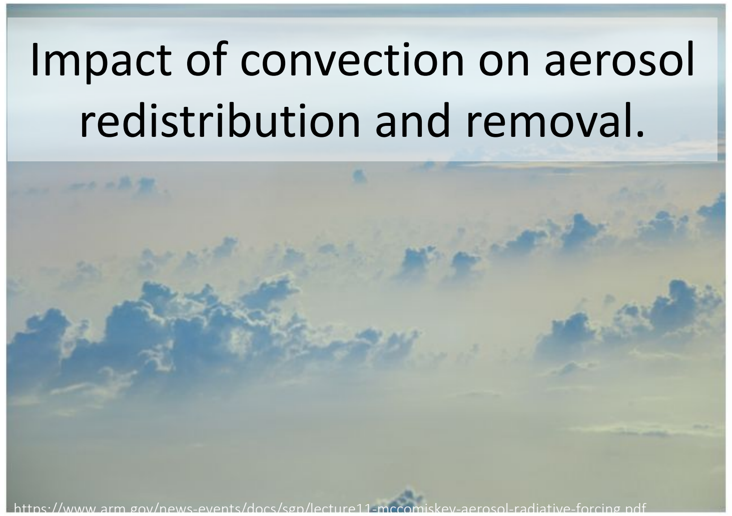
Provide measurements to constrain process level understanding of aerosol-warm/cold and mixed- phase cloud interactions to improve estimates of aerosol indirect radiative forcing.

Minimum Enhanced N/A

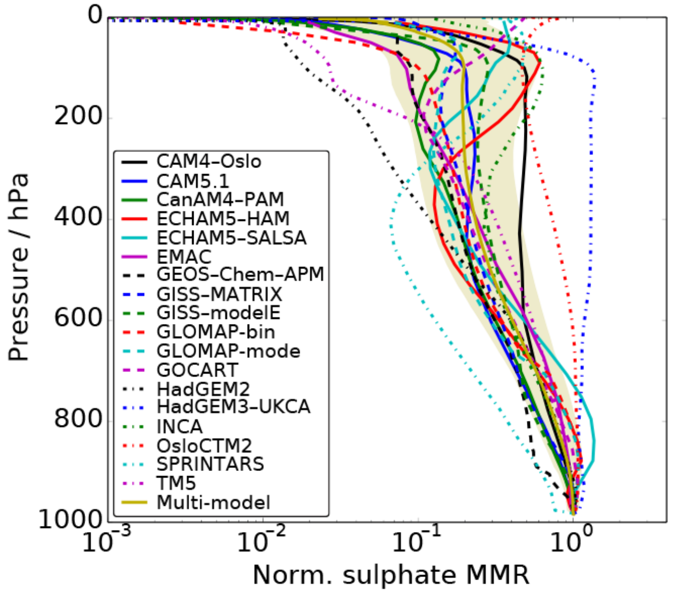






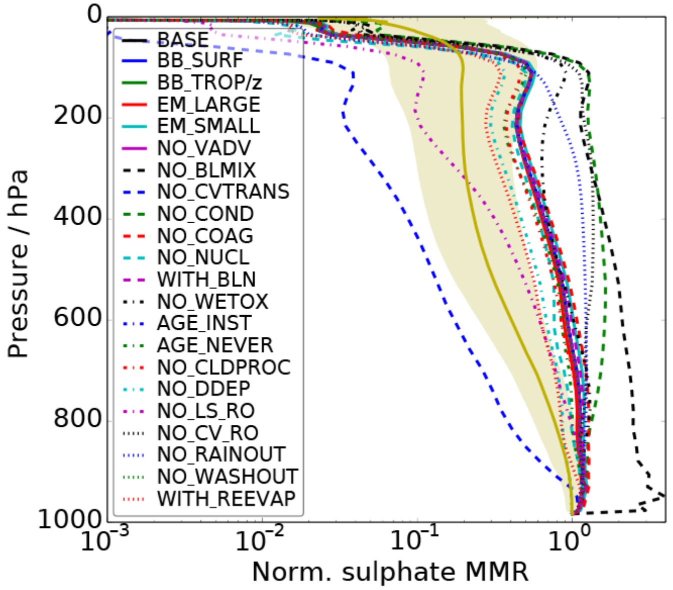


- Single-model "process" simulations produce a spread in type-specific aerosol vertical distribution
- Features in some models not reproduced by single-model simulations → **additional differences between models** (e.g. , convective transport, in-cloud scavenging).



Large differences in aerosol vertical distribution between AeroCom models for various aerosol species.

Kipling et al., 2016



Single-model sensitivity of aerosol vertical distribution to various model processes

Why Sub-Orbital:

Orbital may provide:

- Snapshot of convective stove-pipes
- Aerosol loading/extinction in surrounding regions

Orbital does not provide (well):

- Chemically-speciated aerosol loading
- Cloud microphysics
- Thermodynamic/Dynamic environment
- Time evolution of convective storms
- Tracking of outflow after convective processing

Sub-Orbital focus:

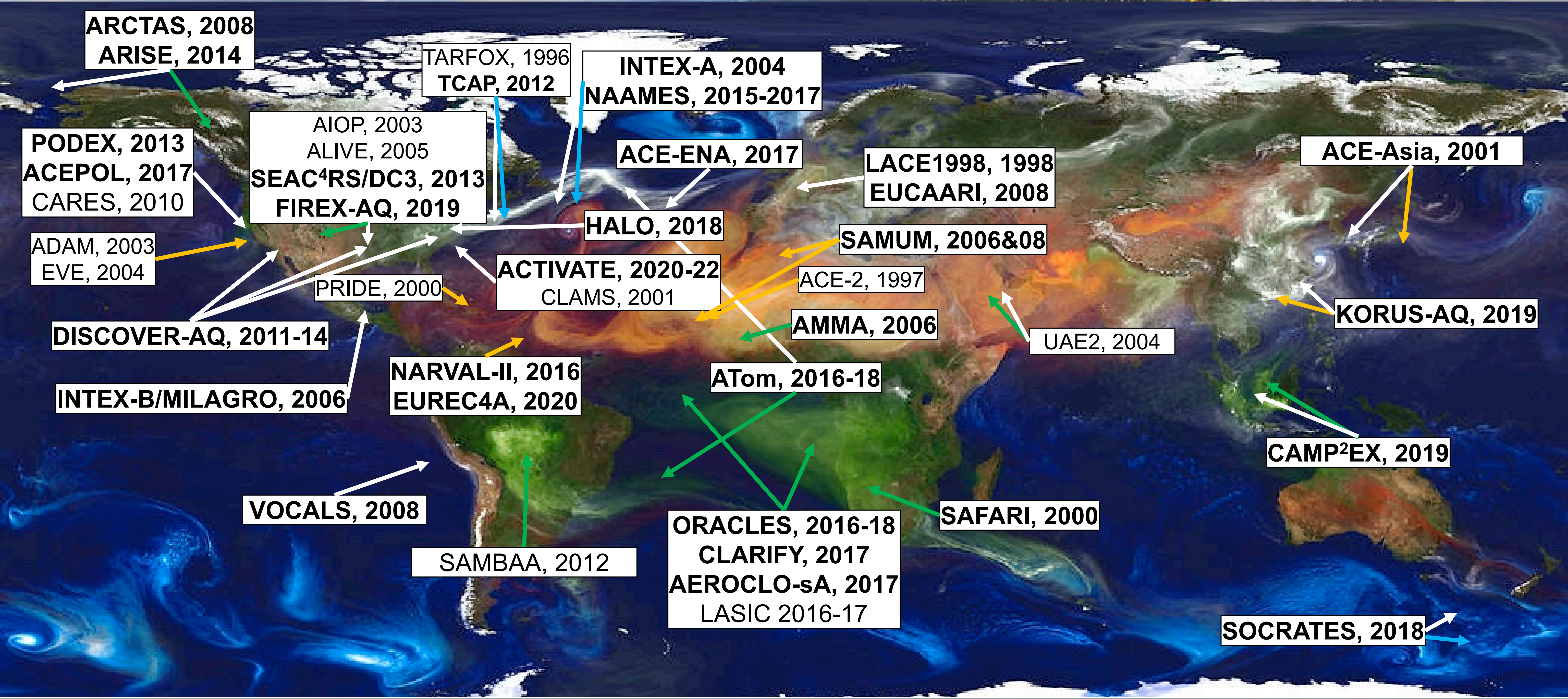
a) Aerosol profile measurements at high spatial and temporal resolutions. incl. chemical speciation
b) Measurements of aerosol sinks and related processes (dry & wet deposition/scavenging)
c) Lagrangian measurements of diffusion and convection of particles, as well as the changes those particles undergo (e.g., 'aging', coating, particle growth)

Multi-Aircraft Campaigns

Focused Single Aircraft

Ground Based Mobile Radar & aerosol in situ

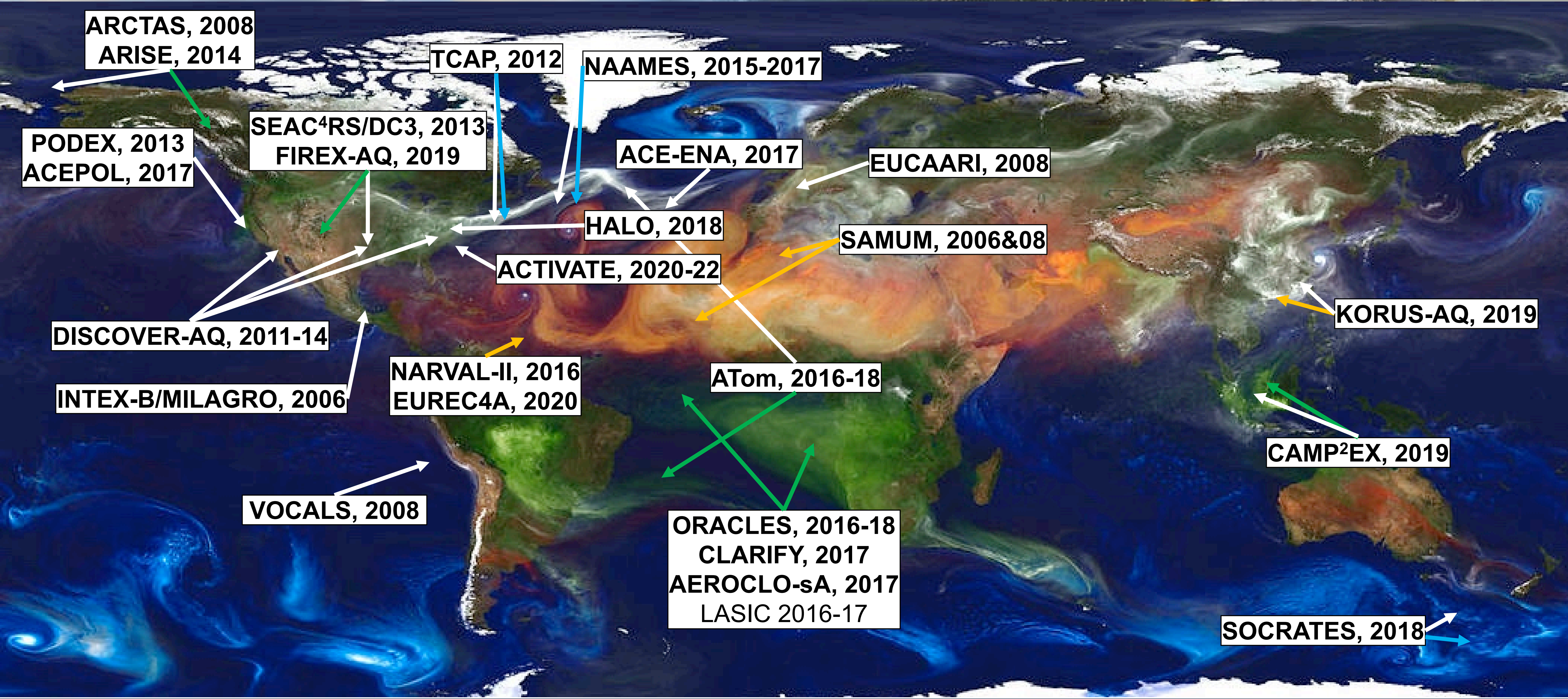
Existing data sets: Major (mostly airborne) Aerosol IOPs since 1996



Colors indicate aerosol type: Biomass Burning, Seasalt, Pollution, Dust   Bold font: most comprehensive

Existing data sets: Major (mostly airborne) Aerosol IOPs since 1996

(i.e., very comprehensive and/or state of the art in situ and/or HSRL + polarimeter)



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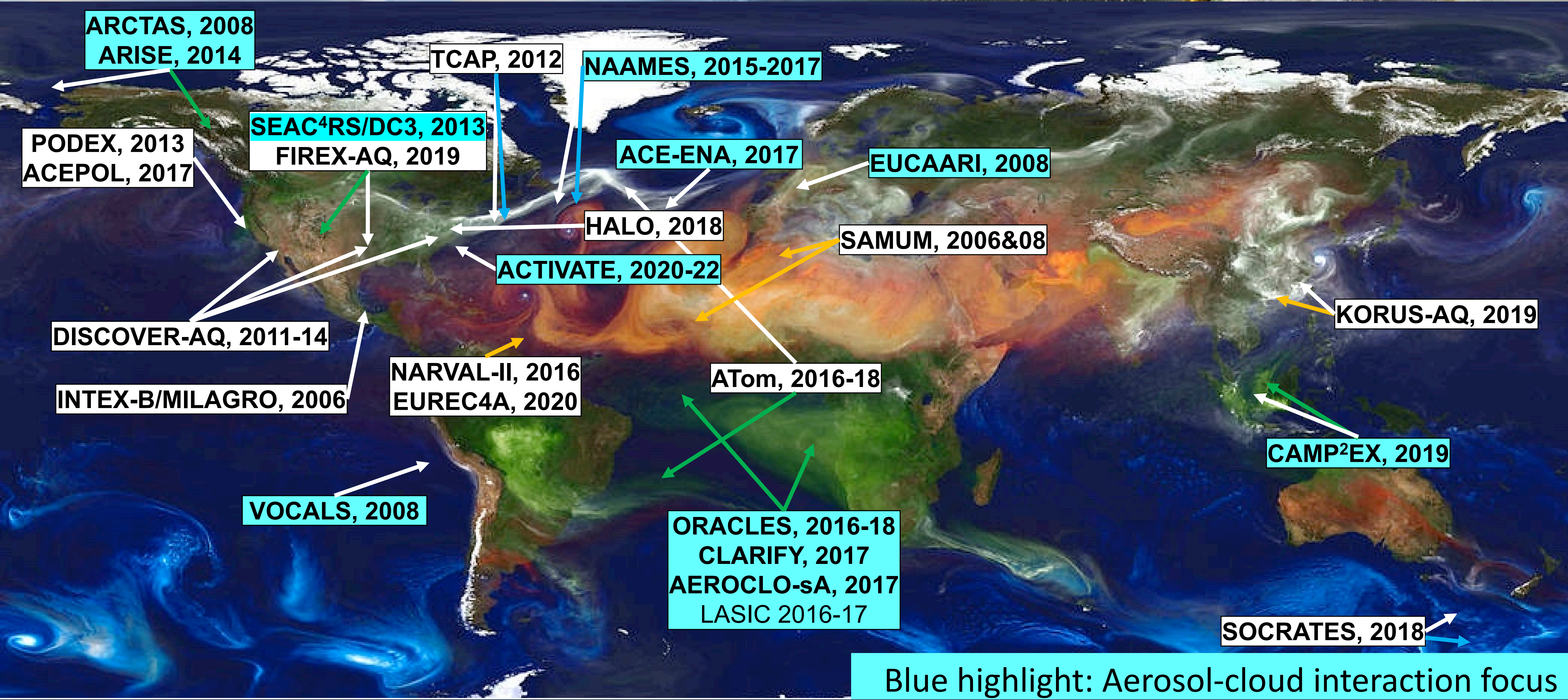

Blue highlight: Aerosol-cloud interaction focus

Colors indicate aerosol type: Biomass Burning, Seasalt, Pollution, Dust   Bold font: most comprehensive

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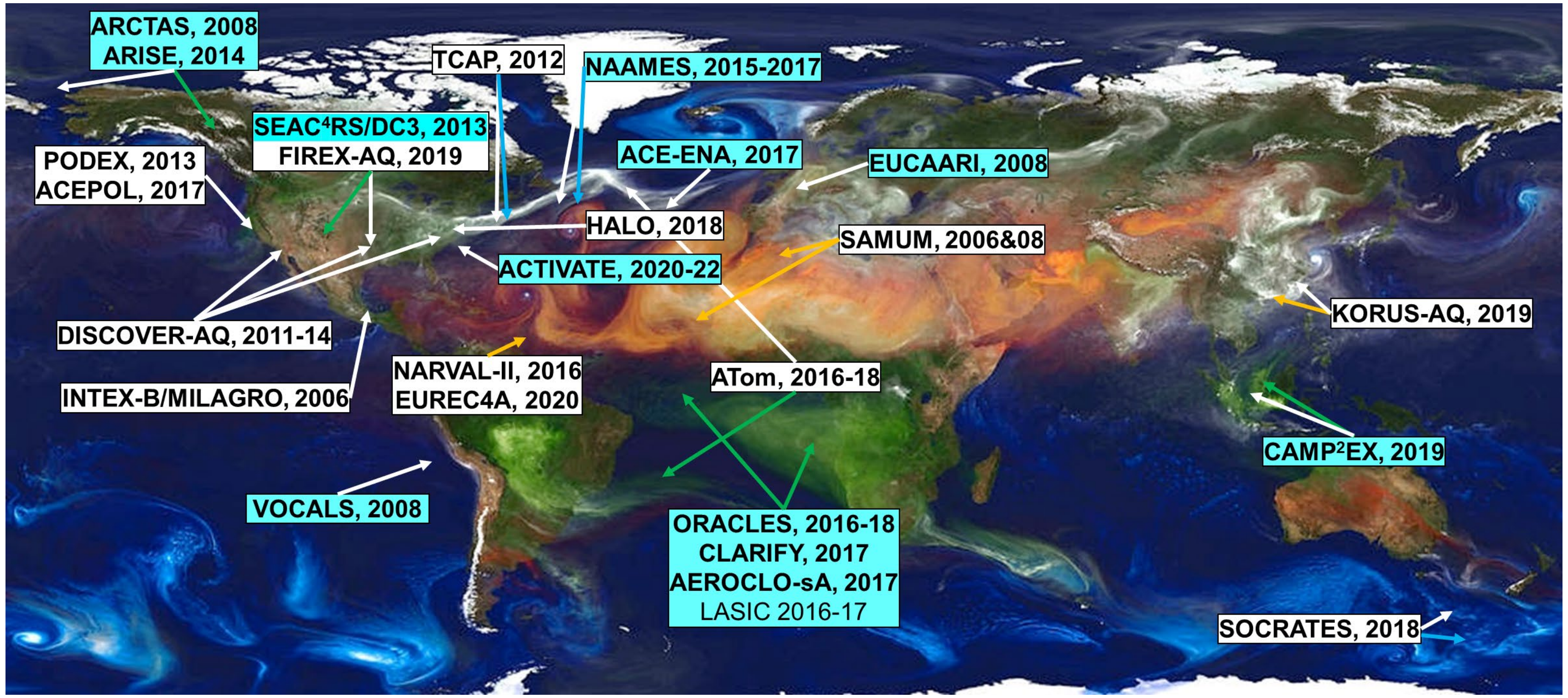


A few thoughts:

- Good distribution (geographically) of biomass burning missions
- Relatively few dust missions, no US
- Relatively few sea-salt missions (inlet?)
- Some comprehensive missions with possibly outdated instrumentation (e.g., ARCTAS, INTEX-B, VOCALS, AMMA)
- Few recent missions focused on multi-species regimes (e.g., polluted dust from Asia)
- ACI campaigns predominantly focused on marine clouds

Colors indicate aerosol type: Biomass Burning, Seasalt, Pollution, Dust   Bold font: most comprehensive

Workshop 2 - Summary

- Extensive list of NASA, NOAA, NSF, DOE, and Int'l Partners airborne campaigns
  - evolved from exploratory studies in the 1990s, 2000s to more systematic, statistically-driven in 2010s
  - statistically-driven studies (e.g., EVSs) are particularly relevant for ACCP
  - datasets remain underutilized; need to leverage these first before spending $$$ on new observations
- Extensive list of ground networks and observational campaigns
  - Opportunities to augment existing networks with additional ACCP-relevant instruments
  - Leverage temporary or mobile ground assets by placing along orbit tracks and during airborne campaigns. ARM mobile facility is a particularly useful asset.
  - Need smaller campaigns with airborne remote sensors on small aircraft. Logistically easier and cheaper. ideal for L1/L2 science data validation
- List of upcoming airborne campaigns in the 2022-2025 timeframe, also next round of EVS
- Many ideas on campaign concepts - some sound like potential Earth Venture Suborbital, 2024-2029 (EVS) proposals.

Workshop 2 – Summary of L1/L2 validation needs

Level 1 Observable/Measurement

A. Total attenuated backscatter (profile)
B. Molecular att. backscatter (profile; HSRL)
C. Total volume depolarization ratio
D. Polarized radiance (vis/IR/submm/MW)
E. Radar reflectivity profile
F. Radar Doppler velocity profile

Program of Record Data Inputs

A. Temperature, Pressure, Humidity profiles (model evaluation)
B. Large-scale and cloud-scale horizontal and vertical winds (model evaluation)
C. Water vapor mixing ratio profiles
D. Precursor gas concentrations

Level 2 Derived Parameters / Retrievals

A. Liquid water path
B. Liquid water content / ice water content profiles
C. Cloud albedo
D. Cloud optical depth
E. Cloud fraction
F. Cloud droplet effective radius
G. Volumetric cloud fraction
H. Precipitation rate
I. In-cloud vertical velocity
J. Aerosol optical depth
K. Aerosol absorption AOD
L. Aerosol backscatter coef. (HSRL)
M. Aerosol extinction coef. (HSRL)
N. Aerosol absorption coef. (spectral?)
O. Aerosol effective radius
P. Aerosol fine mode extinction coef.
Q. Lidar ratio (aerosol extinction:backscatter ratio)
R. Aerosol asymmetry parameter
S. Aerosol-cloud feature mask (should include aerosol layer height)
T. PBL height
U. Aerosol number concentration
V. CCN=f(RH_{water}), IN=f(RH_{ice}, T)
W. Aerosol size distribution
X. Aerosol mass extinction efficiency
Y. PM2.5, PM10
Z. Aerosol type classification
AA. Water vapor mixing ratio and Humidity
BB. Precipitation particle mean size profile
CC. Ice density profile

Algorithm Assumptions and Process Priors

A. Shape parameter of the gamma distribution for precip. Retrieval
B. Multi-modal characterization of ice PSD (single crystals vs. aggregates)
C. Aerosol mass absorption, extinction efficiencies depend on
   a. size distribution
   b. refractive index
   c. Shape
   d. mixing state
D. Cloud adiabaticity and entrainment important for microphysical retrievals
E. Relationships between satellite observables and CCN, IN spectra
F. Sub-grid-scale variability (both for models and satellites)
   a. Sub-grid cloud fraction for wet removal parameterizations
   b. Non-uniform beam filling factor for radars

G. Density-fall speed relationships for ice
H. Ice aspect ratio and orientation distribution as a function of environmental factors and precipitation type (convective/stratiform)

Potential Strategies / Approaches

- Remote Sensing Payload
  - Precipitation and cloud radar
  - High spectral resolution lidar
  - Polarimeter
  - Microwave+sub-mm radiometer
  - Differential absorption lidar (clear air water vapor)
  - Differential absorption radar (in cloud water vapor)
- In Situ Payload
  - Total water content
  - Ice water content
  - Particle size distribution
  - Temperature/humidity/pressure
  - 3D wind
  - Orthogonal ice particle imaging probes
- Airborne (one, or preferably, two planes)
  - Satellite orbit under-flights
  - Intensive process and survey focused field campaigns
  - Validate with in situ the advanced airborne sensors
- Surface-based profiling remote sensing networks
- Surface-based in situ sensor networks
- Tethered balloons
- Connection to geostationary satellites (TEMPO, GEMS, SENTINEL)
- Need to incorporate / account for the retrieval algorithms needed to translate the Level 1 data products into the Level 2 data products
  - verify algorithm assumptions, parameterization inputs
  - good example is precipitation retrievals

Summary

- **SubOrbital is integral to ACCP science** - traceable to Science & Applications Traceability Matrix (SATM), focusing on augmenting and supplementing

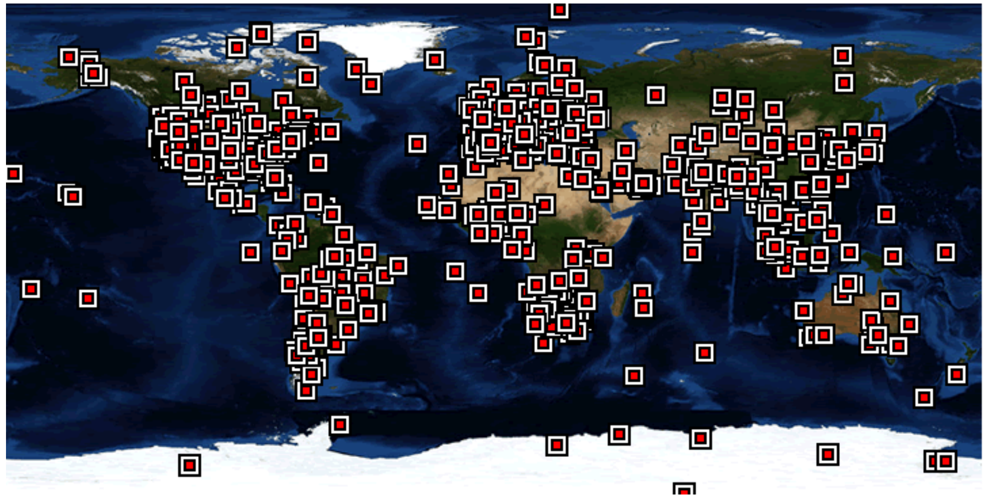
- Diversity of ACCP science: **a spectrum of implementation strategies** from ground-based to multi-aircraft.
  - Emphasis is on strong intra-agency, inter-agency, and international partnerships

- **Science and Implementation strategies modularized** so that ACCP SubOrbital can
  1. Respond quickly
  2. Develop long-term planning for implementation in Phase A

- **Aerosol and Clouds/Convection/Prcp** SubOrbital activities will be highly synergistic and address science as prioritized by broader community

- **Remaining slide are backup**

Aerosol Ground-based networks (remote sensing)



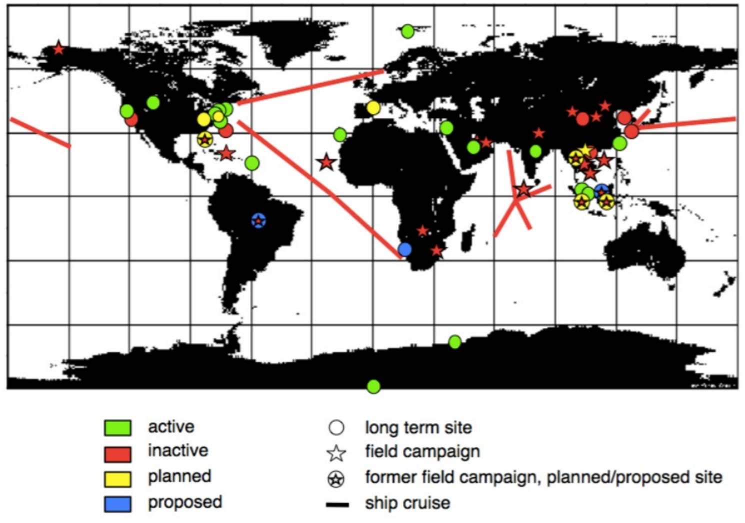
AERONET:

a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (Univ. of Lille 1, CNES, and CNRS-INSU)

SKYNET:

Ground-based radiation network dedicated to aerosol-cloud-solar radiation interaction research

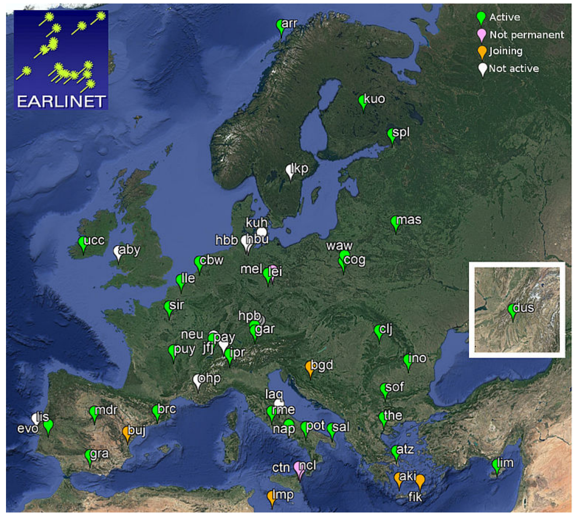
GALION (GAW Aerosol LIdar Observing Network)



* most sites co-located with AERONET

MPLNET:

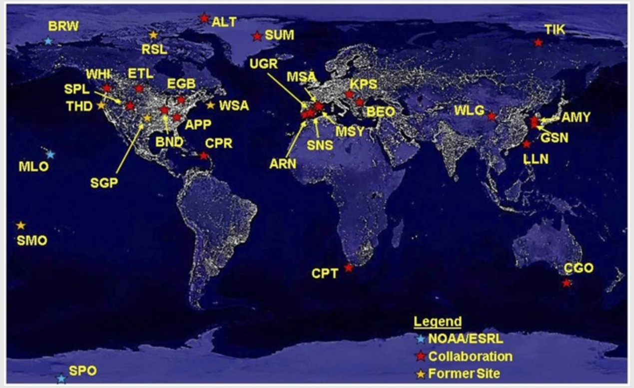
a federated network of Micro-Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure, and boundary layer heights



EARLINET:

established to create a quantitative, comprehensive, and statistically significant database for the horizontal, vertical, and temporal distribution of aerosols on a continental scale

Aerosol Ground-based networks (in situ)



NOAA/ESRL Federated Aerosol Network (NFAN):

monitors surface in-situ aerosol optical properties at field sites around the world

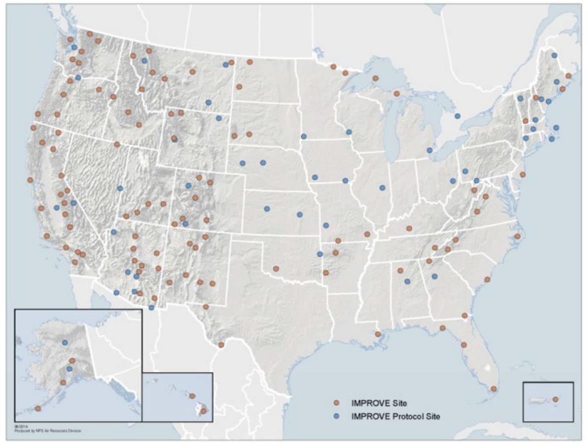
Andrews et al., 2019

ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure Network)

ACSM (Aerosol Chemical Speciation Monitor)

EMEP (European Measurement and Evaluation Programme)

Laj et al., 2020



IMPROVE

visibility monitoring network, measuring speciated PM2.5 composition

WMO GAW

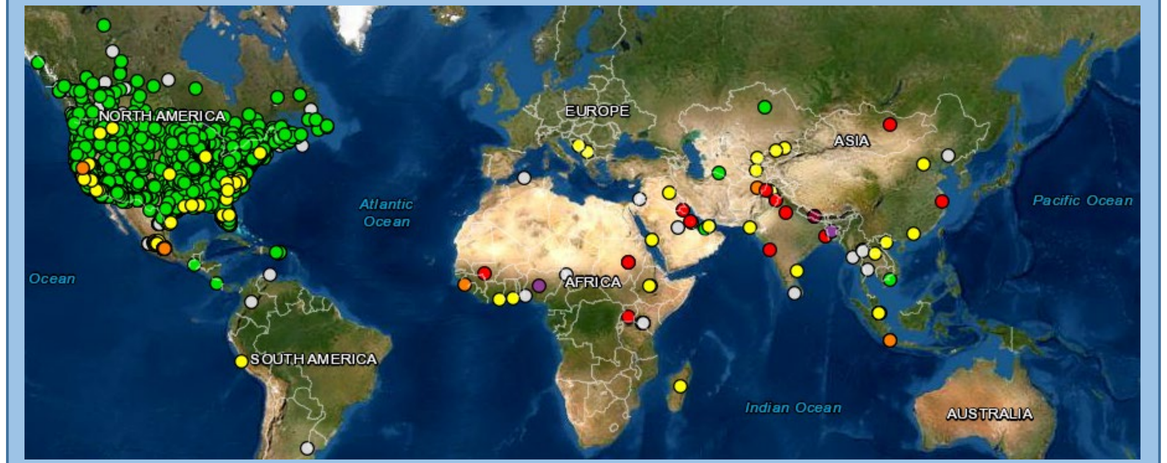
(Global Atmosphere Watch)

AirNow: Air Quality data portal

-One-stop source for air quality data

-CONUS & global; Multiple data sources

-Long-term support; will be expanded



By: EPA, NOAA, NASA, CDC, National Parks, US Forest Service, Nat. Assoc. Clean Air Agencies, Environ. Canada

Various smaller and/or regional networks:

CAPMoN (Canadian Air and Precipitation Monitoring Network) EANET (Acid Deposition Monitoring Network in East Asia)

KRAQNb (Korea Air Quality Network)